**US Army Corps
of Engineers**

Topographic Engineering
Center

Final Report
CPAR-TD-96-2
January 1997

CONSTRUCTION PRODUCTIVITY ADVANCEMENT RESEARCH (CPAR) PROGRAM

Advanced Hydrographic Surveying and Dredging System

by

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DTIC QUALITY INSPECTED 1

19980706 145

AD NUMBER	DATE	DTIC ACCESSION ϽE

1. REPORT IDENTIFYING INFORMATION

A. ORIGINATING AGENCY

U.S. Army Topographic Engineering Center

B. REPORT TITLE AND/OR NUMBER CPAR-TD-96-2
Construction Productivity Advancement

~~XXX MONITOR REPORT NUMBER~~
Research (CPAR) Program

D. PREPARED UNDER CONTRACT NUMBER

2. DISTRIBUTION STATEMENT

Approved for public release; distribution is unlimited.

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DTIC Form 50
DEC 91

PREVIOUS EDITIONS ARE OBSOLETE

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EXECUTIVE SUMMARY

The Topographic Engineering Center (TEC) and Coastal Oceanographics, Inc, initiated a 2-year CPAR Cooperative Research and Development Agreement (CPAR-CRDA) in March 1994. The objective of the agreement was the implementation of new technology and procedures for hydrographic surveying support of the dredging industry. This would be achieved through integration of USACE technology and standards into the commercial hydrographic survey system, HYPACK. The system would also encompass new techniques and procedures previously created in USACE and private industry.

The HYPACK survey system is Microsoft Windows-based software for planning, conducting, editing and publishing hydrographic surveys. The software is used on over 400 vessels in the U.S., 70 of which are Corps boats. HYPACK interfaces to most single beam and multi-transducer acoustic systems, and most positioning systems, including code and carrier phase differential Global Positioning Systems (DGPS). HYPACK also interfaces to various vessel motion sensors, the Roxann bottom classification system, and the Seabat multibeam system.

The TEC and Coastal Oceanographics principal investigators, Tony Niles and Pat Sanders, respectively, identified five technologies for integration or refinement in HYPACK. TEC had previously developed capabilities and/or expertise in each of these areas, and their availability in HYPACK was deemed mutually beneficial to business interests of Coastal Oceanographics and to HYPACK users within and outside the Corps. The development and product integration of each technology was successful, and each capability is now or will soon be available to HYPACK users. The technologies are as follows:

1. Triangulated Irregular Network (TIN) - This terrain modeling technique creates a surface model of the survey coordinates. Any number of data points in any alignment or configuration can be modeled. Comparison of the TIN model with a design surface or another TIN model (i.e. before- and after-dredge surveys) produces volumes. TEC contributed previously developed TIN algorithms and Coastal Oceanographics implemented TIN capability in HYPACK for volume computations and terrain visualization.

2. On-the-Fly DGPS (OTF DGPS)/Real-Time Tides - Coastal Oceanographics modified HYPACK to read position and timing data from the OTF DGPS developed at TEC. The positioning system produces vertical data of sufficient accuracy (2-5 centimeters) to detect tide changes, as referenced to a shore benchmark. TEC conducted a geodetic survey of benchmarks in a test area, Coastal Oceanographics added routines in HYPACK to compute tide level, and the system was tested aboard a

Corps vessel through comparison with conventional tide gage readings. A small systematic error (less than 0.2 foot) was observed, although it could be eliminated with modified user procedures. The tests demonstrated that the automated real-time tide determination using OTF-DGPS is feasible.

3. Multibeam Integration - HYPACK algorithms for use of multibeam systems, which produce multiple sounding beams from a single transducer, were refined to enable more accurate results and efficient editing procedures. TEC contributed recommended procedures and helped evaluate the modified software.

4. Cross-Check - TEC had previously developed software to enable consistency checks of hydrographic survey data and enable compliance with the Corps Hydrographic Surveying Engineer Manual. The software, XCHECK, compares intersecting survey lines collected by single transducer survey systems and computes the vertical differences. This software was provided to Coastal Oceanographics, and similar capability was added to HYPACK.

5. Data Transfer Standard - Coastal Oceanographics added to HYPACK compatibility with Microstation DGN graphics files, which are commonly used in the Corps and other organizations in charting, plotting, and analyses. TEC contributed sample files from Corps districts and DGN decoding routines. Similar compatibility with the S-57 exchange standard will be available to users in 1997.

The HYPACK changes, most of which are now available to users, have had a major effect on the quality and productivity of hydrographic surveys. Users are now or will be able to collect data for virtual total bottom coverage, automatically read tide data, compute more accurate volumes and exchange data more easily and accurately.

INTRODUCTION

The Topographic Engineering Center (TEC) and Coastal Oceanographics, Inc, initiated a 2-year CPAR Cooperative Research and Development Agreement (CPAR-CRDA) in March 1994. Coastal Oceanographics' hydrographic surveying software, HYPACK, was becoming the predominant system used aboard Corps and contractor survey vessels. The software also is used by various other Federal, state and local agencies, as well as commercial firms. Much of the software capability and functionality was driven by Corps requirements, so Coastal Oceanographics had a keen interest in application of technology developed or promoted in the Corps. TEC had significant activities in GPS development, tide datum and water level modeling techniques, and dredge volume algorithms and computation procedures. Use of these technologies would produce the first hydrographic survey system with such capabilities.

TEC similarly had considerable motivation for a CPAR agreement with Coastal Oceanographics. In 1992 TEC investigated development of a standardized hydrographic survey system for the Corps of Engineers. The systems in use at the time had varying accuracies and data collection procedures, and used various computer systems. The districts also sometimes redundantly funded vendors for new capabilities or customization to fit Corps survey procedures. Therefore, under direction from Corps Headquarters, TEC explored contracted development of a new standardized system or modification of an existing system.

After consideration of required funds, contracting issues and time expected to begin fielding a new system, TEC and HQ determined a standardization effort to be non-feasible. Commercial systems with common functions and procedures were migrating to PC-based computers and were becoming available. Furthermore, HYPACK was becoming the predominant system on Corps and contractor survey vessels. Much of the Corps' needs for system capabilities and usability was being met naturally with computer technology and accommodation of user demands.

The CPAR Program offered an effective method to integrate new technology generated at TEC into an existing hydrographic survey system. Therefore, Pat Sanders' CPAR proposal was a timely opportunity for TEC and Coastal Oceanographics. The two year program has been a successful effort in the modification and improvement of the existing software package, HYPACK.

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HYPACK DESCRIPTION

General

HYPACK is PC-based Windows software for planning, conducting, editing and publishing hydrographic surveys. Coastal Oceanographics lists users in 42 countries on a variety of vessels, from 20 foot mono-hulled craft to ocean-going research ships. Within the U.S., HYPACK is used aboard approximately 600 survey vessels, 70 of which are Corps boats or are owned by contractors who conduct surveys for the Corps.

The first version of HYPACK was marketed in 1988, and featured compatibility with various positioning and depth sounding systems. The program included post-processing routines to edit data, incorporate tide information, digitize shorelines, utilize common coordinate systems, and plot results. Subsequent versions have incorporated various dredge volume computation techniques, channel template designs, contouring and terrain modeling, interface to various motion sensors and multibeam sounding systems, real-time tide determination capability, compatibility with the Roxann® bottom classification system, and ability to read and output various graphics files.

HYPACK Functions

The current HYPACK version, 6.4, was released in August 1996, and consists of the functions listed below. Portions that were developed or enhanced in the CPAR project are appropriately annotated and further explained under DEVELOPMENTS:

DESIGN - This function is used to create and configure a planned survey, and display basic information, as follows:

> Display Soundings - Soundings can be displayed in HYPACK or ASCII XYZ format. Contours can be generated in HYPACK'S TIN program and are stored in DXF or Intergraph's DGN format. The user can specify a color contour interval to distinguish various levels of soundings or can color code the data if it has seabed identification information from a system such as ROXANN.

> Display Track Lines - Displays vessel track lines from a specific project.

> Plot Sheets - Plot sheets for specified areas can be created, moved, re-scaled and rotated using point-and-click user interface. Multiple plot sheets can be displayed over a user's DXF base map.

> Planned Survey Lines - Planned survey lines can be created through specification of coordinates of an initial line, then entry of offsets for other lines.

Additional lines also can be generated as parallel, perpendicular or radial offsets to the initial line.

SURVEY - This function conducts hydrographic surveys through interface to and control of various sensors, and according to specifications set in the DESIGN function. SURVEY can handle up to nine different sensors; including positioning devices, echosounders (single & dual frequency, multiple transducer, and multibeam), gyros, heave-pitch-roll sensors, side scan sonars, magnetometers and remotely operated vessel (ROV) tracking systems. SURVEY supports multiple positioning systems including GPS (differential, stand-alone, or kinematic), range/range and range/azimuth systems.

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Area Map - Provides the user with a real-time plan view of the survey. The background file can be either a user supplied DXF or DGN file, or a DGW file digitized from HYPACK's SHORE digitization program. The Area Map also displays the planned survey lines and survey targets marked by the user, and can be used to display the exact perimeter of the survey vessel/dredge/cable barge.

CPAR Development

Data Display - The Data Display in HYPACK's SURVEY program can be configured to display various symbols and alpha-numeric information desired by the user. Font and character size can be specified, and items can be highlighted or enhanced for particular emphasis.

Sensor Display - Each sensor interfaced in HYPACK's SURVEY program has its own chart display, for which the user can control the range, scale and scrolling speed.

Left/Right Indicator - A display for the vessel operator shows the position of the boat's origin relative to the planned survey line. The user can control the scaling of the indicator for individual preferences

Profile Screen - The Profile Screen shows the depth profile, adjusted for tide and draft, and track line for an entire survey line in real time. If available, the channel design template is superimposed over the depth profile to designate areas that are above the design. The Profile Screen also enables instant determination if the actual vessel track deviates from the planned track in excess of the allowable error.

EDIT - The software's editing routines enable complete and detailed analysis and correction of collected data. The main editor provides a graphical user interface for display and edit of trackline, sounding profile and text data, simultaneously. Tide, draft,

heave-pitch-roll and sound velocity corrections can be applied, and soundings can be sorted to prevent overwrites during plotting. Cross-check statistics can also be calculated and graphically displayed.

TIDES - This function permits manual entry of tidal observations with straight line, cubic spline or high/low water computation methods. Automated tide reading and computation also is possible through interface with kinematic differential Global Positioning System (DGPS).

CPAR Development

GEODESY - This function enables the user to convert between various geodetic datums, such as the North American Datum of 1927 and 1983. The GEODESY function also allows various commonly used grid coordinate systems, in metric or English units of measure.

TIN MODEL - This function enables the user to create surface models based on a triangulated irregular network (TIN) from hydrographic and topographic data. Once a TIN has been created, the user can calculate volumes based on comparisons of surface models (survey vs. Survey), surface model vs. channel design, or surface model vs. level (Reservoir). The TIN MODEL function also displays and exports 2-D and 3-D models of depth coded triangles, contours and surface plots, and permits the user to calculate the area within a given contour. This function is particularly useful when dealing with dense, voluminous data from multibeam or multi-transducer systems.

CPAR Development

VOLUMES - HYPACK computes volume quantities from various computation methods, including average end area, prismoidal, contour, and TIN model. All methods provide results according to common dredge practices in the Corps; which include station-by-station volumes, design depth quantities and over-dredge quantities.

CPAR Development

ADVANCED CHANNEL DESIGN - This function enables creation of virtually any channel layout, from straight, constant depth designs to complex turns and wideners. CHANNEL DESIGN is particularly useful when calculating volumes in channels which continually change dimension and have turning basins or wideners.

MULTIBEAM DATA COLLECTION/EDITING - This is an option to the HYPACK package, sold under the name of HYSWEEP. HYPACK allows users to collect multibeam data from the Reson SEABAT, Odom ECHOSCAN, and Seabeam HYDROCHART sweep systems. The HYSWEEP package contains programs to graphically edit the multibeam data and to perform patch tests for sensor alignment.

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Additional Products

Developments and new capabilities in HYPACK have led to two new products.
NAVPACK is Coastal Oceanographics' Electronic Chart System (ECS) for marine
navigation, which displays the vessel's real-time position on a digital chart.
DREDGEPACK is dredge control software, which provides real-time digging
information for bucket, cutter section and hopper type dredges.

CPAR DEVELOPMENTS

Triangulated Irregular Networks (TIN)
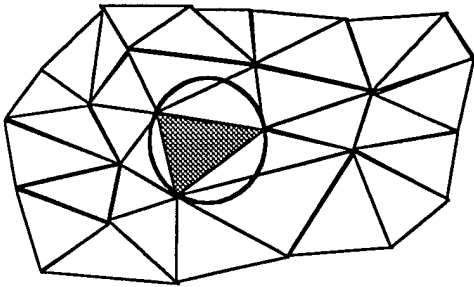
Technology Description

Figure 1; Delaunay TIN

Triangulated Irregular Networks (TINs) are a relatively new method which can be used to calculate dredge volumes. In the TIN method, a terrain model is created through the triangulation of the three-dimensional spatial coordinates. The triangles in this model have no gap and do not overlap. TINs commonly use the Delaunay Principle, in which the TIN is easily determined, is essentially unique, and avoids long, narrow triangles as much as possible. The Delaunay Principle requires that the circle circumscribed around any triangle in the TIN contains no data points in its interior, as illustrated in Figure 1.

Through comparison of TIN models, volumes of material can be determined. In the case of dredging applications, a design model of a channel, consisting of planar surfaces for the floor and side slopes, can be compared with the TIN representing the actual terrain. The TIN triangles are projected onto the design surface, resulting in prismoidal volume elements, as shown in Figure 2. The sum of these prismoidal volumes is the total volume for the area covered by the TIN. Volumes above the design surface would represent material to be dredged, while volumes below the surface represent areas where no dredging is needed or areas for dredge disposal. Similarly, two TIN surfaces, perhaps representing before- and after-dredge terrain, could show actual material that has been dredged or provide accurate information about dynamic surfaces.
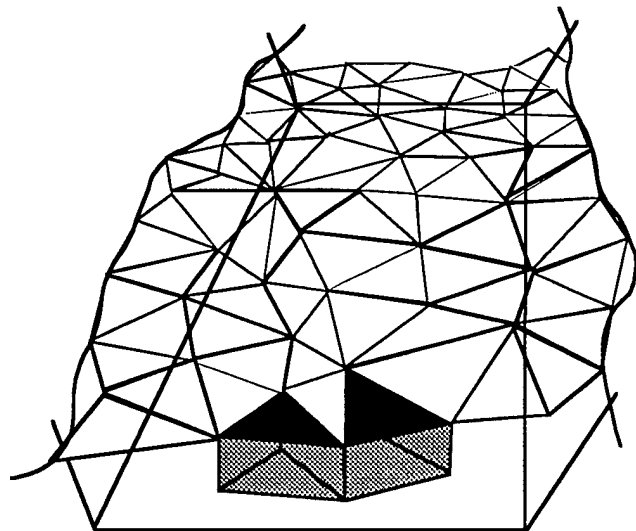

Figure 2; TIN Volume Determination

The TIN method, which can be computationally intensive, has become feasible with the

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availability of modern processors. TIN volume routines are now found in many site design and sophisticated survey software packages. TINs offer the user flexibility in the collection of survey data, since the data need not be aligned along pre-determined cross-section or profile patterns. A detailed analysis of the use of TINs in dredge volume applications was performed by TEC, and is presented in the following section.

TEC Developments

TINs were being used at TEC in the 1980s for military applications involving terrain analyses. Much of the software was original TIN applications developed at TEC or by contractors for the specific uses. TEC scientists, in coordination with mathematics experts from the National Institute of Standards and Technology (NIST), pioneered applications such as terrain visualization, line-of-sight determination, and flow analyses using TIN methods. From these applications, TEC saw potential to compute dredge volumes in civil applications.

The Surveying Division at TEC therefore began a detailed analysis in 1991 of the TIN volume technique which is documented in ETL 1110-2-348, The Use of TINs for Dredged Material Volumes. The analysis, in which NIST participated, included a mathematical examination of the method, comparison with the conventional average-end-area (AEA) technique, and use with several test data sets. The test sets consisted of real and fabricated data representing navigation channel surveys. Among the more significant results, TEC and NIST concluded the following:

1) TIN methods are at least as accurate as, and usually more accurate than the AEA technique. In straight, uniform channels with terrain above the design surface, results are essentially identical. In cases where the terrain extends above and below the design surface, the AEA technique overestimates the volume by as much as 50% or more, whereas the TIN accuracy is not affected.

2) The TIN method uses the survey data more effectively and efficiently. Unlike the AEA method, the data points need not be aligned in parallel cross-sections and can be utilized in any pattern. Multibeam or multi-transducer survey data, which produces virtually total bottom coverage, can be effectively used only with the TIN method. The technique can also utilize combined cross-sectional and longitudinal data, which are recommended for single-transducer systems to perform consistency checks (see Cross-Check Development). Complete utilization of the survey data without realignment or shifting to a required pattern results in more accurate volume results.

3) For the TIN method, verification of results by a manual method is not feasible. In cases of disputes with dredging contractors, Corps of Engineers districts have cited the need to reproduce computed volumes using hand computation or manual drafting methods. Such capability has always been an advantage of the AEA method. However, summing thousands, or even millions of TIN prismoidal volume

elements is essentially impossible. Verification of TIN volumes will only be possible when the technique has gained general acceptance by Corps offices and dredging contractors, and analysis of the utilized TIN algorithm and the user procedures will provide sufficient verification of results. Hopefully, TEC's published results of their TIN analyses will help achieve the acceptance.

4) At the time of TEC's analyses, there were no commercially available TIN software packages specifically designed for dredge volume applications. For example, none of the routines enabled computation of volumes on a station-by-station basis. Most significantly, channel designs that did not consist of a simple, straight configuration could be tedious and difficult to create, and different users might obtain different results. As a result of the TEC/Coastal Oceanographics CPAR, a software package that solves these problems is now available.

Prior to the detailed analyses, TEC and NIST began to develop a TIN software package specifically for dredge volumes. At the time, no commercial TIN routines for general civil use existed and the software, developed with Civil Works Research and Development funds, would be distributed to all Corps offices. However, TIN volume routines began to appear in site design software, such as Intergraph's InRoads application. Therefore, TEC abandoned plans to distribute the TEC/NIST program, and instead used the software for benchmark testing and the analyses described above.

The TEC/NIST routine, in FORTRAN language, was written primarily by the NIST mathematicians who are regarded as authorities in TIN and grid terrain modeling. The software uses a Delaunay triangulation scheme and computes volumes relative to design surface. The software also permits the use of breaklines, which can be used to control triangulation so that prominent features, such as peaks or ridges, are not blunted in the model. The software has no graphical user interface, and uses six to eight input files to define the terrain, design surface and certain tolerances.

Coastal Oceanographics Developments and HYPACK Integration

Prior to the CPAR-CRDA, HYPACK computed volumes with the AEA method. Because of the advantages listed in the previous section, Coastal Oceanographics sought to add TIN modeling capability. Coastal Oceanographics thus used algorithms in the TEC TIN software to create such a routine in HYPACK. The TEC algorithms offered a robust TIN generation module, although the user interface and data input procedure were crude and cumbersome, and were incompatible with the HYPACK software. Coastal Oceanographics therefore developed graphical interfaces and adapted the TIN routines to read coordinate files from HYPACK. Coastal Oceanographics also re-coded much of the computation sections and modified the data structures for faster and more efficient run time.

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Once development of the TIN routine was complete, Coastal Oceanographics developed terrain visualization algorithms and dredge volume capabilities. A contour algorithm using B-spline smoothing was integrated, along with the flexibility of user-defined color designations. The result is compatibility to generate plan-view plots showing user-defined contour intervals or 3-D perspective plots showing realistic terrain undulations, as in Figure 3. For volume calculations, Coastal Oceanographics developed a channel template routine that enables the user to specify angular vertices and/or side slopes. Using this procedure, channel designs, which can include any combination of turns, wideners, depths and side-slopes; can be easily entered with the completed layout displayed for review, as shown in Figure 4.

Following Coastal Oceanographic's integration of the TIN routines, TEC performed tests using the benchmarks data sets used in their previous analyses. Volumes were compared with those obtained from the TEC/NIST routine and InRoads. Results between the three routines were very close, as is shown below, and the HYPACK routine required far less time than the other two to create the design surfaces. Run time of HYPACK was generally 100% - 130% of InRoads, and 25% - 50% of the TEC/NIST routine:

Test 1: This test data is from a survey of a channel with a 45° turn and a widener. Data was collected on cross-sections approximately 100 feet apart. Channel width (toe to toe) is 80 feet. Three different design depths are considered, and the results, in cubic yards, are -

Design 1 (38 ft. depth)	TEC/NIST - 5074.5 InRoads - 5073.4 HYPACK - 5073.2 Maximum difference - 0.02%
Design 2 (40 ft)	TEC/NIST - 7089.2 InRoads - 7087.2 HYPACK - 7087.6 Maximum difference - 0.03%
Design 3 (42 ft)	TEC/NIST - 11732.0 InRoads - 11729.7 HYPACK - 11729.7 Maximum difference - 0.02%

Test 2: This test data consists of points in a 10ft by 10ft grid and shows a flat surface of 50ft depth. The design surface has 1:1 side slopes and a base of 100 ft depth.

TEC/NIST - 277777.8   InRoads - 277777.8
HYPACK - 277777.8
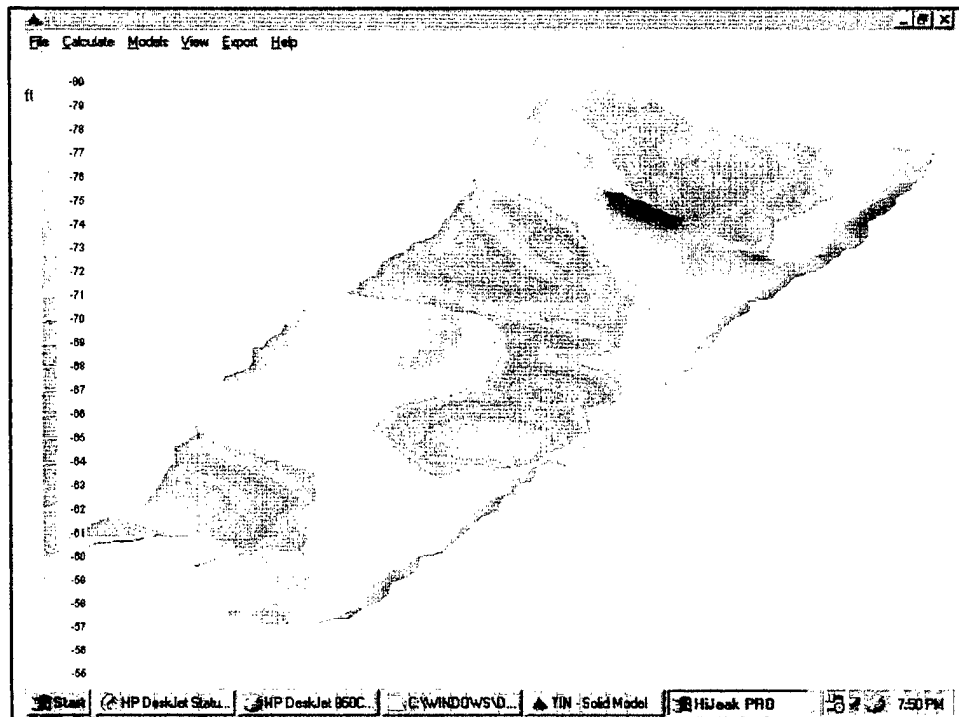Maximum difference - 0.0%

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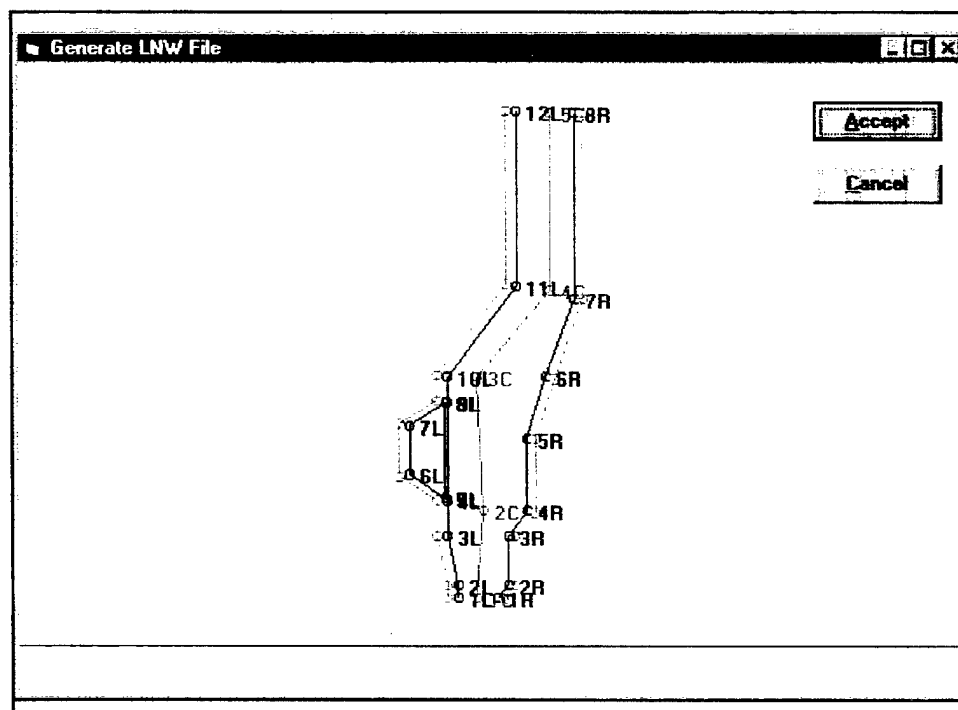Figure 3; TIN Menu in HYPACK

Figure 4; Channel Design Menu in HYPACK

Test 3: Data is from a survey of a straight channel, 390 feet wide with 1:3 (rise:run) side slopes. The data was collected with a single transducer system running 18 uniformly-spaced longitudinal lines. Designs 1 and 2 specify two different channel depths. Design 3 is a sloped template specifying increasing depth in the direction of the channel. Design 4 has an oblique slope, both in the direction of the channel and of the channel toes.

Design 1 (40 ft)   TEC/NIST - 614005.2   InRoads - 614005.0
HYPACK - 614005.5
Maximum difference - 0.0%

Design 2 (38 ft)   TEC/NIST - 156700.7   InRoads - 156693.1
HYPACK - 156700.8
Maximum difference - 0.005%

Design 3 (channel slope) TEC/NIST - 18399.7   InRoads - 18399.7
HYPACK - 18399.7
Maximum difference - 0.0%

Design 4 (channel and toe slope)   TEC/NIST - 91181.9
InRoads - 91182.1
HYPACK - 91181.1
Maximum difference - 0.001%

Test 4: This test data consists of points in a 12 foot grid, representing a surface initially sloped, then horizontal at 90 feet. The design surface with 1:1 side slopes, parallels the terrain surface with a constant offset on 30 feet.

TEC/NIST - 57911.1   InRoads - 57906.0
HYPACK - 57911.1
Maximum difference - 0.009%

Test 5: This test data is a survey of a turning basin. The data was collected using longitudinal and cross-section lines; each line approximately 50 feet apart. The design surface is a depth of 50 feet with 1:3 side-slopes.

TEC/NIST - 17691.3   InRoads - 17691.5
HYPACK - 17694.2
Maximum difference - 0.016%

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OTF-GPS Integration and Real-Time Tide Capability

Technology Description

The NAVSTAR Global Positioning System (GPS) is a satellite-based technology that enables 3-D positioning anywhere in the world at any time. The system, developed by the Department of Defense, is primarily to provide a Precise Positioning Service (PPS) to the U.S. military and its allies. GPS also provides the Standard Positioning Service (SPS), a service available to civilians with the purchase of necessary equipment. These services are enabled by the transmission from the satellites of time-coded signals unique to each satellite, and information on satellite timing and positions. By measuring the arrival time of these coded signals, a GPS receiver estimates the range to each of the GPS satellites in view. Using the satellite positions, the receiver computes its own position on the earth's surface.

Each satellite broadcasts information through two frequencies, L1 and L2. On each frequency, coded messages (the P-code and C/A code) are modulated or carried. Both the carrier frequency and the coded messages are used to obtain positioning information. Figure 5 shows the signal structure.

Carrier	Codes		
	Civilian	**Military**	
L Band	C/A Code	P Code	Satellite Message
L1 (1575.42 MHz) 19 cm wavelength	Present 300 m wavelength	Present 30 m wavelength	Chipping Rate is 50 bps
L2 (1227.60 MHz) 24 cm wavelength	Not Present	Present 30 m wavelength	

Figure 5; GPS Signal Structure

When using one GPS receiver, the 3-D absolute accuracy is approximately 16 meters for PPS and 100 meters for SPS.

Differential GPS (DGPS) techniques process signals from two GPS receivers operating simultaneously and determine the 3-D vector between them. When one of the receivers is established over a known location, this unit becomes a reference station and can be used to enhance the accuracy of the position of the receiver at the unknown, or rover station. This technique can be used with the code phase information

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transmitted by the GPS satellites to obtain meter accuracy or the carrier information to obtain an accuracy to a few millimeters. The range of accuracies using a single receiver and differential techniques is shown in Figure 6.
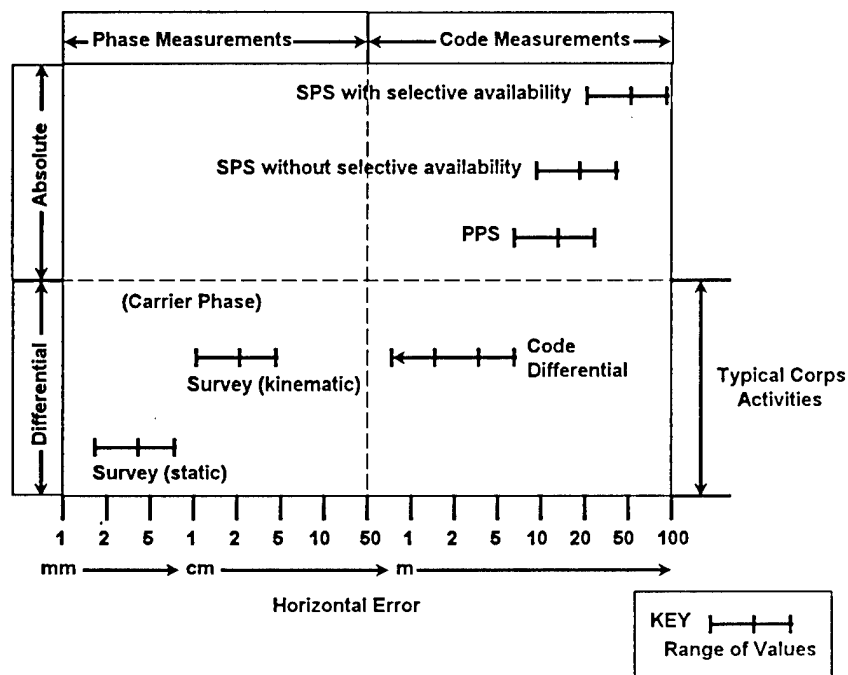

Figure 6; GPS Accuracies

The code differential technique is commonly available in commercial receivers and has become the predominant method of positioning for hydrographic surveys in the Corps and most other agencies with such activities. Through a cooperative agreement, the Corps and the U.S. Coast Guard have established a network of permanent reference stations, based on the Coast Guard's radio beacon broadcast, along most of the nation's navigable waterways. Therefore, users need only one GPS receiver and a radio beacon receiver to achieve 1-5 meter accuracy.

TEC Developments

In the past, the accuracy to which a moving platform could feasibly be positioned using DGPS was limited by the code differential technique. Achieving sub-meter accuracy requires use of the carrier phase signal. In differential applications, this has had strict operational constraints; namely, the requirement to initialize at the reference station when beginning data collection or when a satellite signal is lost. Such dependency on reference station initialization before and during survey missions renders carrier phase techniques, and thus sub-meter positioning accuracy, non-feasible for hydrographic surveys.

In 1988, under funding from the Corps Dredging Research Program (DRP), TEC began a six-year effort to develop a centimeter-accuracy DGPS-based positioning system that would be free of the reference station initialization procedures. The resulting system that was developed uses carrier-phase signals, can be used on a moving platform, and can be used in real-time. Unlike previous DGPS implementations, the DRP system resolves the ambiguity in the integer number of satellite signal wavelengths without initializing over a known location. The integer ambiguity can be determined while in motion, or "on-the-fly", thus enabling positions of centimeter accuracy in a variety of applications. These positions are possible over a range of approximately 20 kilometers. Figure 7 shows the hardware configuration for an On-the-Fly (OTF) system. The OTF real-time system requires dual frequency (L1/L2) geodetic GPS receivers capable of receiving full wavelength carrier phase measurements during Anti-Spoofing (AS) (AS is the encryption of the P-Code on the GPS signal).

Coastal Oceanographics Developments and HYPACK Integration

The availability of an accurate vertical positioning system can simplify and produce greater accuracy in the process of water level computations during survey procedures. Using the OTF DGPS from TEC, Coastal Oceanographics developed such a system and performed tests onboard the USACE Baltimore District Survey Vessel *Linthicum*. Figure 8 shows the Baltimore Harbor test area. The following sections describe the methodology and developments used in the tests.

Conventional hydrography determines a chart depth by measuring the distance from the sounding transducer to the bottom, adding a correction for draft, and then removing a portion of the water column which represents the height of the water above the sounding datum (tide correction), as shown.

If OTF-DGPS is used, the entry of tide gage readings into the survey processing can be eliminated. Chart depths are computed, as follows:
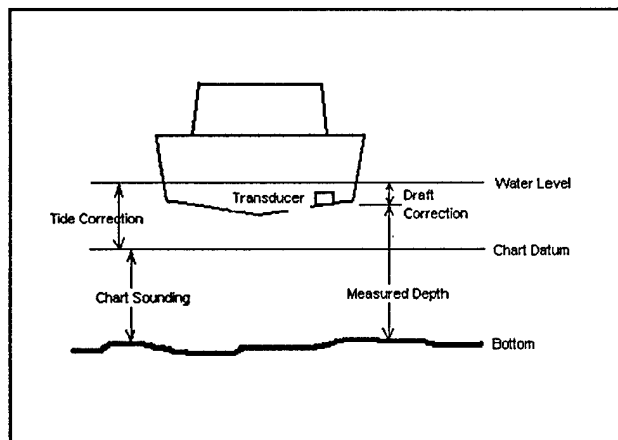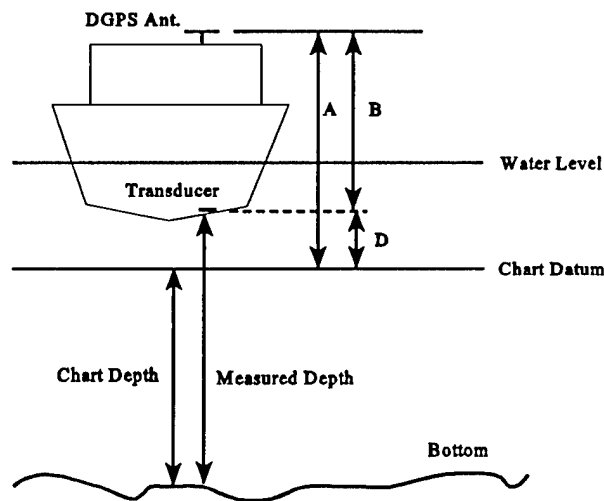
A = Height of DGPS Antenna Above the Chart Datum
B = Separation Between DGPS Antenna and Echosounder Transducer
D = Height of Transducer Above Chart Datum
CD = Chart Depth
MD = Measured Depth

CD = MD - D
CD = MD - (A - B)

The measured depth is received from the echosounder, and there is no need for a draft correction to be entered into the sounder. (A small draft correction may be necessary to calibrate the echosounder so that a plate 5 feet below the transducer plate gives a reading of 5 feet and the same plate 25 feet below the transducer gives a reading of 25 feet. This is an adjustment for the electronic draft of the sounder and does not affect the above process.)

The separation between the DGPS antenna and transducer, for the Baltimore tests, was physically measured at 21.80 feet. HYPACK calculated the exact offsets based on the pitch and roll information from a TSS-335 motion sensor. Maximum roll/pitch during the testing was less than 2.5°, which reduced the height separations by less than 0.02 feet.

The DGPS ellipsoid height differences were received from the OTF-DGPS at update rates of one per second. For kinematic processing, the height differences were interpolated for depths between pairs of adjacent OTF-DGPS updates.

The height of the chart datum above the OTF-DGPS datum was determined by interpolating a table of surrounding values. Previously, TEC performed a geodetic survey of the four local tide stations. This survey determined precise geodetic ellipsoid height differences between the gages, and the survey was referenced to a benchmark at Station *Fort 2, 1988*. These differences enabled chart/OTF-DGPS datum comparisons, for which the values were as follows:

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Station	Reference Station Ht. Above Chart Datum at the Station Mark
Fort 2, 1988	-8.97 ft.
Armstead, Ref 2, 1934	-9.47 ft.
BM No 3, 1959	-9.66 ft.
MB 3364 B, 1983	-10.37 ft.

The values were plotted and a contour chart was created. The survey area was then gridded and values were picked from the contour chart for each node of the grid, as shown. These values were entered in a Kinematic Tidal Diagram (KTD) which was searched and interpolated in real-time. Based upon the current vessel position the height of the chart datum above the OTF-DGPS datum is determined in real-time and saved with the position data. Each value was also shown on the screen in the OTF-DGPS data display in HYPACK.
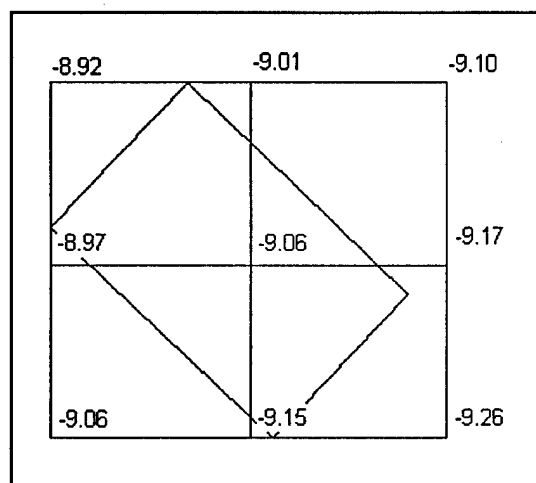
The above area was contoured and a KTD grid box placed around the survey area. The values used for the nodes were determined from the function:

$$f(x,y) = x^2y^2 (9 - 6x - 6y + 4xy)$$

which was obtained from MathCad Version 4.0, which provides the weighting function approach for approximating an irregular surface from uniformly spaced data. Once HYPACK determined the position of the vessel in XY coordinates, the program determines the appropriate grid cell. HYPACK then calculates the value for the ellipsoid/chart datum separation using function shown.

The test survey was conducted near Fort McHenry, which is where the OTF-DGPS reference station was established. An area map is shown in Figure 8. The harbor has a normal tide range of 4.0 feet. Hydrographic survey data was collected using a single-beam echo-sounder and a heave-pitch-roll compensator interfaced to HYPACK. This data was then processed in HYPACK using conventional tide data (observed every ten minutes from the gage at Ft. McHenry) and processed separately using the elevation information from the OTF-DGPS to determine the height of the transducer without need of tide data.

To check the positional accuracy, two passes were made across the same line. This

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was performed to ensure that the various devices were being properly time-tagged. Overlaying the resulting profiles, a timing error would be apparent if the profiles did not overlay.

Each line was edited two times. The first time they were edited with conventional processing methods (measured draft + draft correction - tide correction). The second time they were edited with kinematic methods (measured draft + DGPS/transducer separation height - OTF-DGPS datum height - OTF-DGPS datum/chart datum separation). The resulting edited data for the two lines was then plotted on the same graph and statistical analysis were run on the data sets.

Over 6,000 soundings were collected on a set of ten survey lines covering approximately 960,000 square feet. Comparison of data from the two processing methods showed an average difference of -0.18 feet that appears to be the result of a systematic error. Possible causes are:

Rover Set

Radio Link

Dual Frequency Receiver

Differential Processor

Nav/Differential Data

Kinematic Data

Base/Reference Set

Dual Frequency Receiver

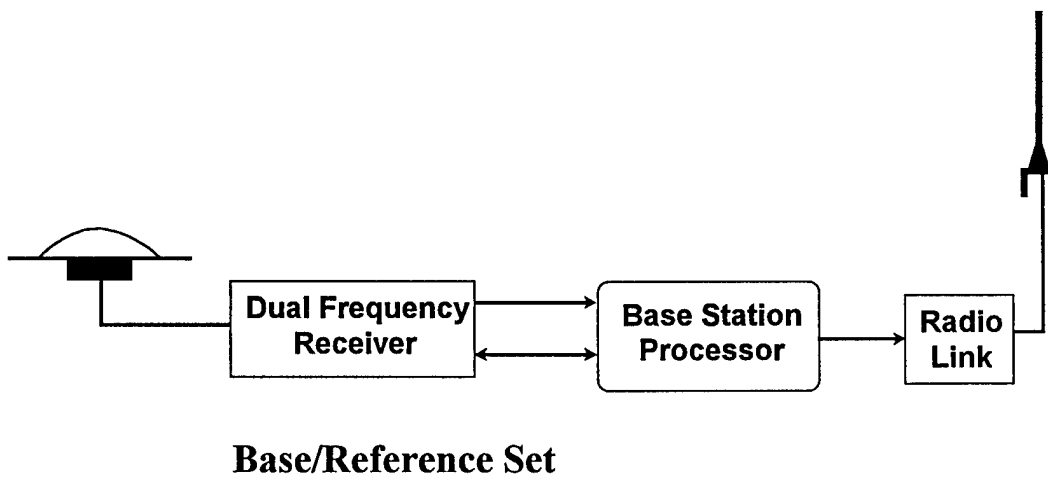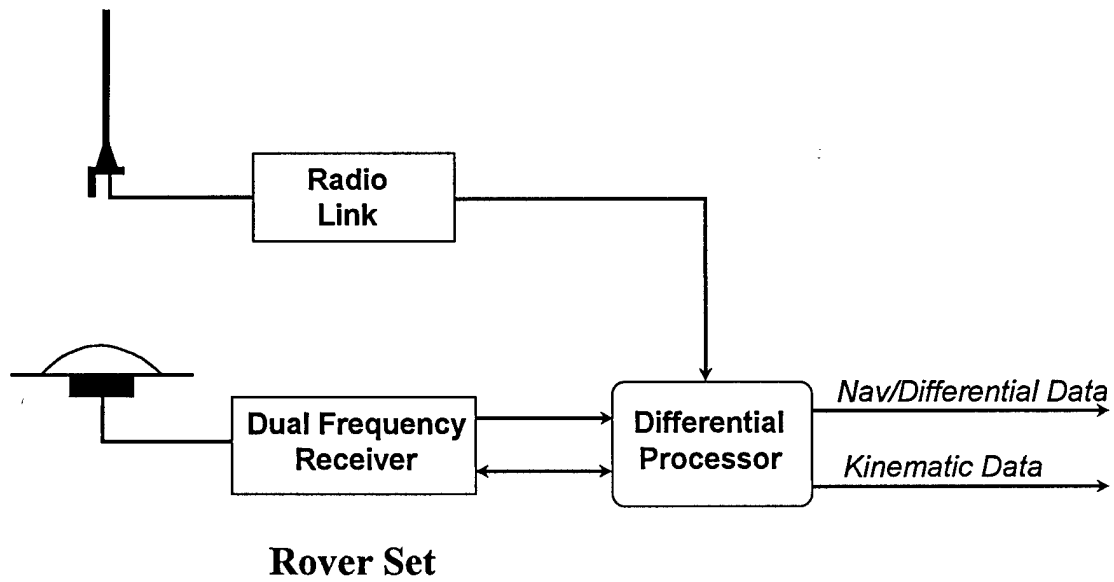Base Station Processor

Radio Link
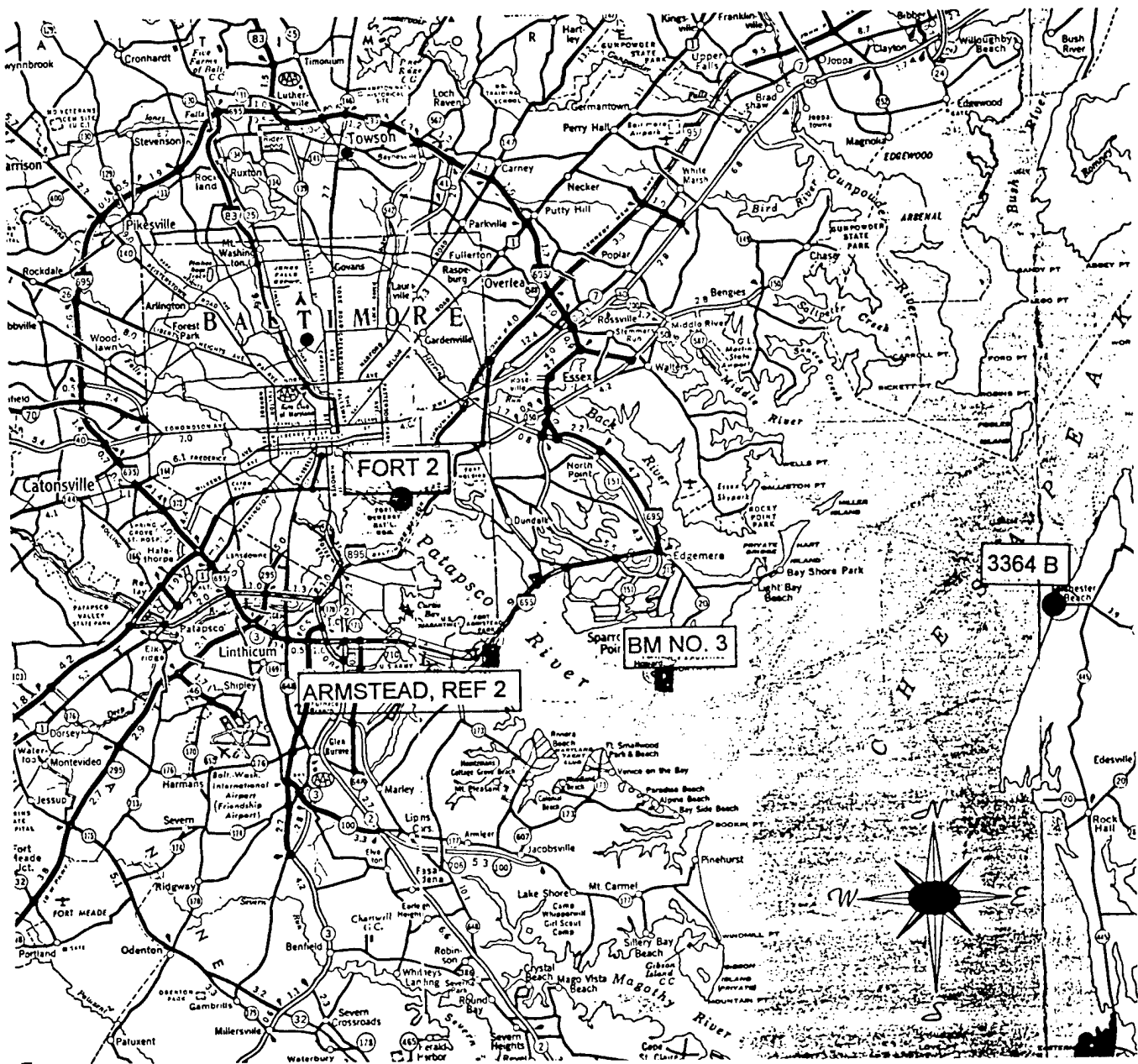
Figure 7; OTF DGPS Hardware Configuration

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Figure 8; OTF-DGPS Test Area in Baltimore Harbor

- Error in measurement of the separation between the DGPS antenna and the sounding transducer. This measurement could be effectively accomplished only with the vessel out of the water, which was not possible for this test.

- Error in calibration of the echosounder. For these tests, the normal 2.1 feet of draft correction used on this vessel was set to "0", and calibration was overlooked after making this change.

- Disregard of possible vessel squat.

- Inaccuracy of MLLW at Fort 2 gage.

Since the 0.18 feet difference was evident in every survey line, it is concluded that additional tests could identify and eliminate the error source. Such "lessons learned" would be included in HYPACK product documentation, USACE manuals on tide issues and/or training forums.

When the systematic error is removed, the sounding differences (feet) have the following distribution range:

0.2 to 0.3	0.4%
0.1 to 0.2	1.6%
0.0 to 0.1	46.3%
-0.1 to 0.0	42.7%
-0.2 to -0.1	8.3%
-0.3 to -0.2	0.4%

These results show the real-time tide method with OTF-DGPS to be very close to tide levels determined using conventional readings from gages. The differences are well within the accuracy of acoustic sounding methods and the Corps standard for Class I dredge payment surveys (0.5 foot).

Multibeam Integration

Technology Description

Multibeam sounding technology is rapidly replacing single beam sounding in areas where 100% bottom coverage is necessary. In single beam sounding, a single sonar beam with a width from 3° to 8° is used to measure the depth. The area of bottom which is actually examined is very small and is dependent on the depth and the beam angle. Multibeam sounding allows the user to measure up to sixty depths along a narrow swath. The swath can cover from 90° to 120° beneath the hull of the survey vessel. These measurements are made up to 14 times per second, providing users with millions of soundings per day of survey. To provide 100% coverage, the spacing between survey lines is dependent upon the depth below the vessel and the width of the multibeam scan. Multibeam technology also provides an extremely valuable reconnaissance tool for performing real-time examinations of breakwalls, dikes, levees, bridges and other structures.

TEC Developments

TEC began analyses of multibeam systems in 1989 with a test and evaluation of the Bathyscan system produced by Marconi, Ltd, of England. The Bathyscan was the first multibeam system developed for shallow water (under 100 feet) and featured some innovative beam forming and backscatter detection techniques. However, the on-board data processor used late 1970's technology, which produced slow data logging and limited processing capabilities. Data editing was tedious. TEC recognized the need for more robust data processing and system calibration procedures, and 3-D graphic editing to enable effective analysis of tens or hundreds of thousands of data points.

TEC performed a second test and analysis in 1992 of the German Atlas Fansweep system, installed and used by John E. Chance and Associates (JECA), Inc of Louisiana. The system performed well and demonstrated the ability to perform multibeam surveys to Corps Class I hydrographic survey accuracy standards. However, the JECA system used customized data collection and processing algorithms on a Unix data processor. During the tests, acoustics experts and system programmers were present to operate the system and make software modifications as needed. Although the system gave JECA impressive capability as a survey contractor, such expertise is not available on Corps vessels. Until the software was available on common processors, i.e. PC-based computers, multibeam technology did not appear to be feasible for Corps vessels nor a majority of contractor boats.

With such multibeam analyses experience, TEC participated with Coastal Oceanographics to develop standard procedures for multibeam operation, such as the patch test described in the following section. The timing of these developments was favorable, since PCS were becoming powerful enough to perform sophisticated

processing yet retain an effective user interface.

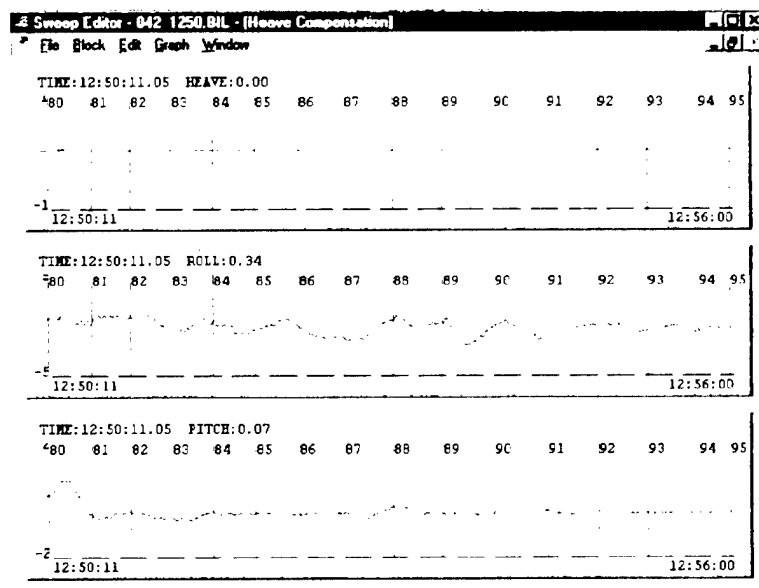*Coastal Oceanographics Developments and HYPACK Integration*

The integration of multibeam editing and sensor alignment in HYPACK had already begun prior to the start of the CPAR. Development was accelerated due to its inclusion in the CPAR. The multibeam editing program, named HYSWEEP, was transferred from the DOS to Windows operating platforms. This eliminated restrictions of the amount of data due to memory and provided an easier environment for the operator.

Users first load a multibeam file into the HYSWEEP program and then examine the trackline, heave-pitch-roll, gyro, tide and draft corrections included with the data. Sound velocity correction data can also be incorporated at this point to correct for "ray-bending" caused by variations in the speed of sound through the water column on sound waves which are not parallel to the bottom. Once these inputs are examined and verified, the user calculates a discrete X,Y,Z for each measurement. The number of coordinates can be enormous, since nearly 1,000 depths per second are collected in multibeam systems.

A 3-dimensional editor is then used to examine the data and to eliminate questionable points. Users can manually edit the data, or use one of several automated filters available in the package. Figures 9 and 10 show the HYSWEEP and data editor in HYPACK, respectively.
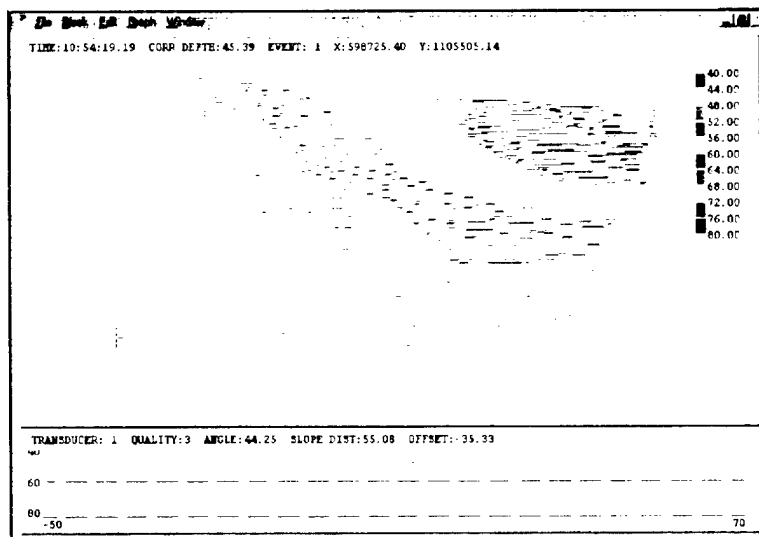
Once the data has been edited, users can save to either a binary X,Y,Z,Beam Angle file or an ASCII XYZ file. These files can be reduced in the MAPPER program, which has gridding routines, or they can be read directly into the TIN MODEL program for surface generation and volume computations.

Due to the problems in verifying mounting angles and timing delays between different pieces of equipment, the PATCH TEST program was developed in late 1995 to assist users in calibrating their multibeam systems. This program allows users to determine errors in mounting in the roll and pitch axes and the delay between the navigation and multibeam system measurements. It also determines any error detected in the sensor (gyro) alignment. To maximize error detection, predetermined tests are used. For example, to determine the roll mounting error, users log survey data over a flat area of the channel in opposite directions. These files are then loaded into the PATCH TEST program to show the statistical range of soundings as the roll mounting angle is altered through a range of values. Where the range is a minimum is the actual mounting angle. Soundings can either be post-processed with the mounting angle corrections added, or users can configure their hardware to run with the correct angles. Figure 11 shows the patch test in the HYPACK program.

TIME:12:50:11.05 HEAVE:0.00

80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95

-1
12:50:11   12:56:00

TIME:12:50:11.05 ROLL:0.34

80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95

-5
12:50:11   12:56:00

TIME:12:50:11.05 PITCH:0.07

80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95

-2
12:50:11   12:56:00

Examining Heave-Pitch-Roll data in HYSWEEP.

Figure 9

File Block Edit Graph Window

TIME:10:54:19.19 CORR DEPTH:45.39 EVENT: 1 X:598725.40 Y:1105505.14

40.00
44.00
48.00
52.00
56.00
60.00
64.00
68.00
72.00
76.00
80.00

TRANSDUCER: 1 QUALITY:3 ANGLE:44.25 SLOPE DIST:55.08 OFFSET:-35.33
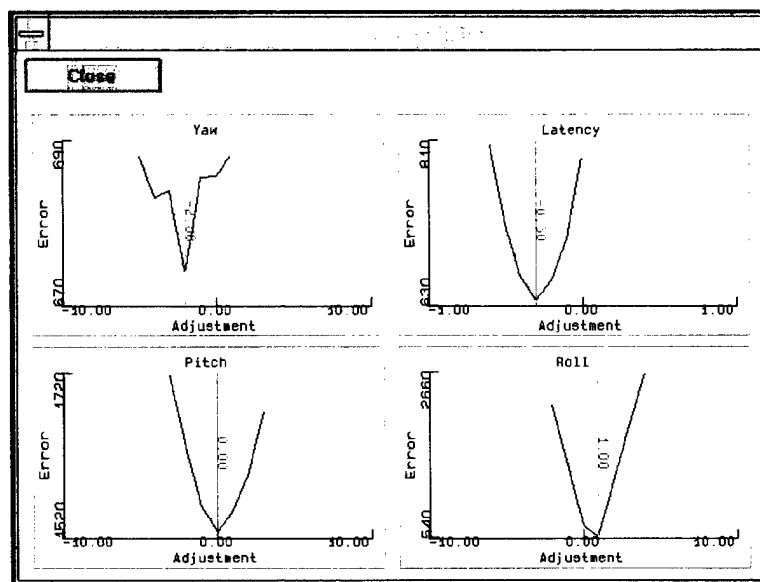
60

80
-50   70

3-D Sweep Data Display for Editing in HYSWEEP.

Figure 10

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Results of PATCH TEST of multibeam data.

Figure 11

Cross-Check Data Editing

Technology Description

Hydrographic surveys using single beam transducers are post-processed to remove errors, such as erroneous soundings and position data. A test that can detect less obvious errors and some biases is the cross-check procedure. In this test, overlapping survey lines, usually perpendicular to each other, that are collected during different sessions, are compared. Deviation between the depths of the overlapping lines indicates inconsistencies in the survey, and the need for further analysis and editing, or possibly the need to re-survey. This procedure is recommended in EM 1110-1-1003, Hydrographic Surveying.

TEC Developments

In 1993, TEC developed the DOS-based program XCHECK for analysis of hydrographic survey data from single beam echosounders. This software, developed under the Corps Civil Works Surveying and Mapping R&D Program, was distributed to districts throughout the Corps. XCHECK reads survey data, in the form of ASCII coordinates, from two different files. The data is divided into survey lines, which is determined by a tolerance in spacing and change in direction between consecutive points. Lines from the two files are then analyzed for horizontal intersections. Where intersections are found, the vertical differences are computed. The screen output then specifies the number of intersections, and the average and standard deviations. The output file additionally gives the coordinates for the start and end points for each line, and the coordinates of the intersections.

Coastal Oceanographics Developments and HYPACK Integration

TEC provided recommendations based on the XCHECK program, and Coastal Oceanographics developed a similar routine with added capability, which was added to the EDIT function in HYPACK. The Statistics program searches through edited data files and computes the difference in final soundings where survey lines intersect. The user defines a "search radius" at the beginning of the program and provides a list of files to be used. The Statistics program searches for any intersection of the survey data which is within the "search radius" of a planned line intersection. Results are then graphically shown. A statistical distribution of the data is also available for display and printing. A sample output is shown in Figure 12.
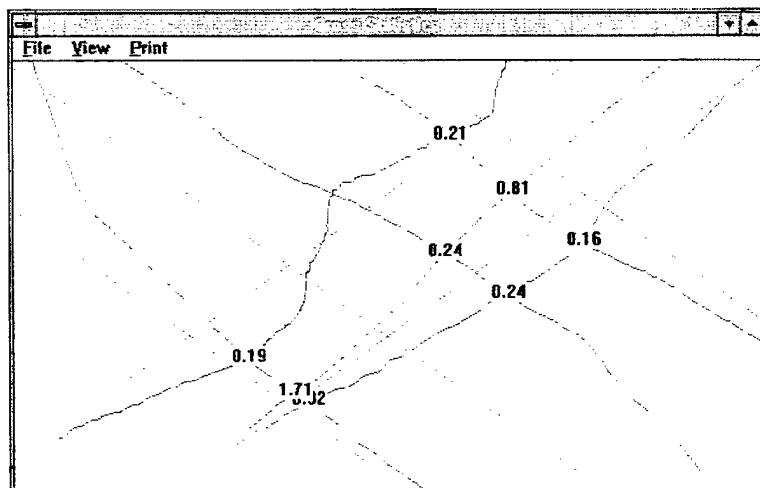
Sample display of intersections from STATISTICS.

```
                              ***
                              ***    2
                              *** ***          1
                              *** ***        ***
-----------------------------------------------------------------------
-18s -9s -8s -7s -6s -5s -4s -3s -2s -1s +1s +2s +3s +4s +5s +6s +7s

Date: 10-06-1995
Time: 08:12:41
Cross File: C:\COASTAL\HKT\EDIT\NORMAL.LOG
Section File: C:\COASTAL\HKT\EDIT\CROSS.LOG
Number of possible intersection 9
Intersection has been found in 8 cases
Search radius 50
Arithmetic mean m=0.561163
Standard deviation s=0.516201
```

Cross Check Table	007_1214.hkt z1 z2 dif	008_1145.hkt z1 z2 dif	008_1149.hk z1 z2
003_1210.hkt	22.62 21.70 0.92	21.03 19.32 1.71	18.28 18.09
004_1200.hkt	19.98 20.22 -0.24	19.60 19.36 0.24	n/a n/a
006_1202.hkt	18.38 18.54 -0.16	18.63 19.44 -0.81	19.34 19.13

Statistical data from STATISTICS Program.

Figure 12

Data Transfer Standard

Technology Description

As hydrographic survey data files become more detailed and contain more information, the complete and unambiguous exchange of data with other users, particularly outside the surveyor's organization, becomes more difficult and complex. The receivers of the data may use different data processing software, and therefore may not be able to read the proprietary graphics format used by the producer. Computer-aided design and drafting (CADD) systems commonly import and export open graphics standards, such as DXF, although some information (text fonts, closed contour lines, etc.) Is usually lost in the process. Non-graphic attribute information; such as date of survey, accuracy of coordinates, geographic datum; usually involves other files for transfer, or other means, such tabulated lists, referrals to standards, etc. Much of the attribute information may not be transferred at all, resulting in an incomplete data exchange.

The proliferation of geographic information systems (GISs) with the extensive spatial databases has led to the development of data exchange standards. Standards such as the Spatial Data Exchange Standard use relational structures to store information for objects in a theme; i.e. topography; along with attribute information. For hydrographic survey and related bathymetric data, no such exchange standard has yet been established in the U.S. The International Hydrographic Organization has developed the S-57 standard (formerly known as DX-90), primarily for charting applications. Various international customers of Coastal Oceanographics support the S-57 standard and have requested such export capability in HYPACK. In the U.S., various commercial navigation interests have requested hydrographic information from the Corps for electronic charting applications. The format for this data that is commonly requested is S-57. Therefore, TEC and Coastal Oceanographics determined that an S-57 output capability in HYPACK is needed.

TEC Activities

TEC has analyzed the S-57 standard and its possible application to Corps hydrographic data. Experience was first gained in 1993 with participation in the U.S. Electronic Chart Display and Information System (ECDIS) Testbed Project. In this effort, the Corps' Lower Mississippi Valley Division, Waterways Experiment Station and TEC participated with other Federal and commercial organizations to test international ECDIS standards. TEC and WES established a first-ever ECDIS implementation on the Mississippi River using Corps data. The project raised an awareness of discrepancies between S-57 object catalogue/attribute standards and common data elements in Corps data. It was evident that an extension of the S-57 catalogue was needed to accommodate the large-scale, detailed data.

With such a background in Corps hydrographic data, TEC and Coastal Oceanographics agreed to cooperatively develop common data exchange capability in HYPACK. The effort would begin with complete compatibility with the Microstation DGN graphics format, which is commonly used by Corps offices, contractors, and other HYPACK users. TEC gathered various DGN files from Corps districts and file decoding algorithms from Intergraph and provided the files and modules to Coastal Oceanographics. TEC also developed metadata files for the sample Corps data to guide development of the attribute translations into S-57.

Coastal Oceanographics Developments and HYPACK Integration

The initial focus of Data Transfer Standards was placed on the import and export of Microstation DGN files into HYPACK. Changes to the DESIGN and SURVEY program made in early 1995 allow users to import basic DGN drawing elements (lines, polylines, text, points) into the area maps of both programs. As sample DGN files were provided from more districts, other drawing elements (B-splines, complex curves, circles and arcs) were incorporated. A sample DGN file from HYPACK is shown in Figure 13.
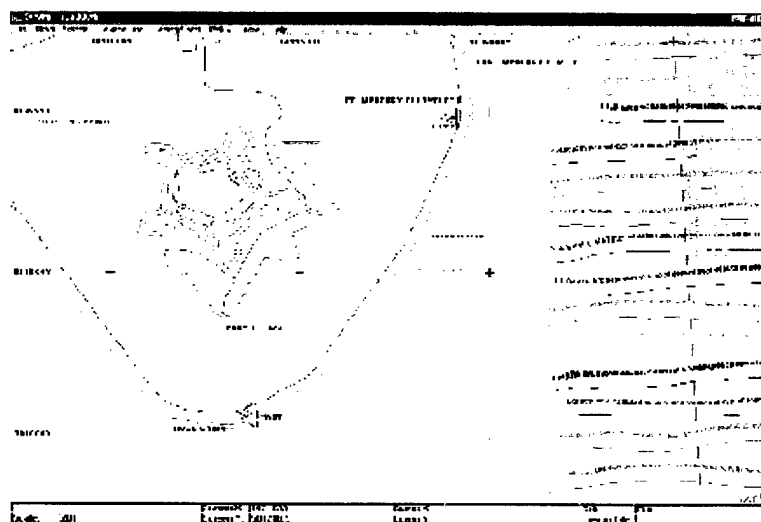
Fort McHenry from USACE-Baltimore in HYPACK's
DESIGN program.

Figure 13

The second phase of integration was to allow export of HYPACK data directly to Microstation DGN files. HYPACK's REFORMAT program was modified in Version 5.9 (released September 1995) to allow for direct output of soundings, track lines, planned survey lines, digitized shoreline information, targets and plotting sheet layouts directly to DGN format. This allows the users to "paste" HYPACK data directly on their previously prepared base maps.

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The third phase of integration was the creation of Metadata files in HYPACK. Metadata is sometimes termed "data about data"; such a file contains a detailed description of survey data. Using the "Content Standards for Digital Geospatial Metadata" information provided by USACE-TEC, work began in late 1995 to create a detailed, user-friendly program to allow users to create Metadata files. The structure of this module was established and development of the program code was started. However, the task of writing the program was underestimated; development of the various sections, sub-sections and linkages proved tedious and time-consuming, and completion was not possible by the conclusion of the CPAR. Coastal Oceanographics reports that the program should be completed and available in the next HYPACK release (Version 6.10 planned for February 1997).

The final phase of integration is the S-57 program for inter-agency data exchange. This program will allow users to translate HYPACK and Microstation DGN files directly to the S-57 Cartographic Database Format. It will also allow users to import S-57 format files and convert them to HYPACK and Microstation DGN format. The conversion program is still under development and its initial release is scheduled for the October 1996 HYPACK 6.10 version. The S-57 program will be an important tool for users who wish to provide their data for electronic chart providers and who wish to utilize cartographic data from other agencies. The Metadata program developed under the third phase will be incorporated directly into the S-57 translation program. The S-57 translation program is being prepared to use "attribute" (feature) data assigned to each object. Users can create these attributes in Microstation using an Oracle or similar database product.

COMMERCIALIZATION

All accomplishments from this CPAR project have been or will be incorporated into the HYPACK program. Status of the individual accomplishments is as follows:

TIN Volume Routine

TIN volume routines have been incorporated into HYPACK and distributed to users. The initial TIN routines were included in the Version 5.2 release, February 1996, with basic channel design capability. An improved TIN routine was released in Version 6.4, August 1996, which includes color and shading visualization, color contour fill in 2-D and 3-D, and optional export of DXF graphical images. The latest version also uses a B-spline smoothing technique when producing a TIN plot in HYPACK's plotting program, HYPLOT.

OTF-DGPS/Real-Time Tides

The use of OTF-DGPS for Real-Time Tides has been a standard part of HYPACK since the release of Version 5.9 in September 1995. Although its use has been limited to survey agencies with severe tide problems, recent inquiries show that several USACE Districts are making plans to utilize this function. Coastal Oceanographics plans to issue a training workbook in October 1996 which will provide simple illustrations on how to incorporate this technology.

Cross-Check

The STATISTICS program for comparison and analysis of cross-check soundings was incorporated into HYPACK in Version 5.2, which was released in February 1996. This program is used mainly by national hydrographic offices who are officially required to run cross check lines, and by the few USACE surveyors who also incorporate cross check lines in their surveys. Work on this program is complete and no further improvements are planned.

Data Exchange Standard

Export capability for the S-57 hydrographic data exchange standard is expected to be released in a 1997 HYPACK version. Coastal Oceanographics developed translation capability for basic sounding information and ability to translate basic geometric shapes, but without attribute data. In a separate effort, Coastal Oceanographics is building upon the basic translation function and is adding attribute information and will be able to read the features in the Tri-Service Spatial Data Standard Hydro category. The software will also be able to display S-57 data in DXF or DGN files.

Import and export of graphical data in the Intergraph DGN format was accomplished. This format is extensively used by Corps districts in engineering and operations functions, and will enable much more efficient exchange of information with survey crews. The DGN import and export capability was incorporated in Version 5.2, which was released in February 1995. Significant improvements were made in the Version 5.9 release (September, 1995) to incorporate various drawing elements used by USACE districts and contractors.

The main hindrance to translation of data elements to a standard exchange format, such as S-57, is the prevalence of numerous user-defined elements. Development of a translator that converts all, or even most of the various symbols developed by HYPACK users to a common format is essentially impossible. Either each user must define his/her data symbols and attribution scheme to completely translate to another standard, or users must begin using a common data dictionary. Within USACE, the latter is being pursued through the Tri-Service Spatial Data Standards. Version 1.6, to be released in 1997, will have a hydro category with over 100 elements to represent various features in both inland and coastal waterways. The hydro standard was compiled from various USACE charting symbols and schemes, the S-57 Standard, and commonly used symbols on nautical charts produced by the National Oceanographic and Atmospheric Administration. Note that these standards are also to be mandatory for USACE, as directed in Engineer Regulation 1110-1-8156, Policies, Guidance, and Requirements for Geospatial Data and Systems. Future revisions of the EM 1110-1-1003, Hydrographic Surveying, should reflect the Tri-Service Data Dictionary in the Automated Data Processing Criteria and Engineering Drawings and Charting Criteria sections.

The Coastal Oceanographics S-57 translator will read the Tri-Service Hydro Standard data elements. Therefore, surveyors who use this standard will be able to translate all graphic elements in survey charts or files with minimal user intervention. This translation capability will be available to all users, and HYPACK will either include the Tri-Service hydro cell library or will reference internet sites where this data can be obtained.

PRODUCTIVITY BENEFITS

The changes made to the HYPACK software programs, incorporating the work performed under this CPAR, have had a major effect on the quality and productivity of hydrographic surveys. By the end of 1995, the benefits of the CPAR work had been distributed worldwide. The only CPAR tasks remaining were the March 1996 workshop demonstrating the CPAR developments and the final project report. Current estimates of the number of HYPACK users who are benefiting from this work include:

- 70 Corps survey vessels
- 50 other Federal vessels
- 300 private vessels in 180 U.S. companies
- 180 foreign users

The incorporation of the TIN MODEL program comes at a time when industry is shifting from the Average End Area to more accurate TIN volume computations. It also provides a means for computing volumes for data collected with multiple transducer and multibeam systems. The capability of making and manipulating 3-dimensional surface models allows users to quickly visualize survey data, which can provide a quicker and more reliable method of checking for erroneous data or blunders. The 3-D visualization also enable fast detection of significant terrain features, such as scour holes or revetment failures, without exporting the data to another terrain modeling program. The could save as much as 50% of the time in data analysis. An added bonus is the benefit of 2-dimensional and 3-dimensional contouring which is now a standard part of the package.

The integration of OTF-GPS for Real Time Tide Capability is only beginning to be accepted by industry. This technology allows for users to eliminate the time and expense of constantly monitoring traditional tide gauge networks. It also provides for precise tidal data in areas where gauges are not mounted or where the tide recorded at the gauge does not accurately reflect the changes in the water level surface in the survey area.

The integration of Multibeam Editing and Patch Test capabilities into HYPACK has already benefited USACE and industry. The HYPACK/HYSWEEP combination is used for producing charts and for examination of engineering structures. HYSWEEP is now in use on USACE platforms in Los Angeles, Wilmington, Louisville and Sault Ste. Marie. Over 20 packages have been sold to industry, with the majority of them coming from overseas survey agencies. HYPACK/HYSWEEP is the first tool which allows USACE users to compute volume quantities from multibeam data. It has reduced processing times of multibeam data from 8:1 (eight hours processing for every one hour of multibeam data) to 1:1 (one hour of processing for every one hour of multibeam data).

The Cross-Check Analysis routine built into HYPACK now provides a quality control tool which gives the hydrographer an excellent indicator of the accuracy of the survey. Sounding comparisons which would take weeks of post processing to compile can now be performed before the equipment leaves the survey site.

The Data Exchange Standard routines will allow for outside agencies to easily transform USACE survey data to their in-house formats, and vice-versa. The conversion to S-57 will be a cornerstone for incorporating USACE survey data into electronic charts. Being able to import Corps base maps in Microstation DGN format directly into HYPACK has accelerated the design phase of surveys and also provided valuable reference information during data collection. Being able to export edited HYPACK data directly to DGN format has reduced the time needed to go from "field to finish" and allows users to "paste" current survey data directly onto base maps.

CONCLUSIONS AND RECOMMENDATIONS

The HYPACK software has become quite popular with many government and commercial organizations involved in shallow water hydrographic surveying. The program uses the common PC computer platform and Microsoft Windows operating system, is upgraded with new technological developments with no additional cost to existing users, is available at a reasonable price, and broad technical support is available from Coastal Oceanographics. This CPAR has produced several additional capabilities that are or will soon be available to users. These developments offer greater accuracy, efficiency and standardization in collection and processing of hydrographic survey data in support of dredging operations. As with all survey tools, the CPAR developments and the HYPACK software itself, should be considered for application in the context of the user's requirements, expertise and resources available.

The TIN volume capability now available in HYPACK offers more complete utilization of survey data and more accurate computation of dredge volumes. The collected data need not be shifted to specific alignments, as in the average end area method, and the TIN method is the only feasible method to use relatively large dense data sets, as would be produced with multibeam systems. Tests of the HYPACK TIN routines indicate that the program produces accurate results, and the volumes differ with other known routines by less than 2%. Note that extremely large datasets, i.e. more than 100,000 points, may require several hours processing time or may be impossible to process. Such datasets may need to be thinned or divided into smaller sections. As with any computationally intensive application, the faster computers, i.e. Pentium PCS over 133 MHZ clock speed, with Windows 95 or Windows NT operating system will perform better.

Government and commercial HYPACK users are encouraged to begin using the TIN routine. The terrain visualization function can be an effective method for detecting survey blunders. If different parties are computing volumes for the same project, as with contractor/customer dredge projects, then template specifications and control parameters for the TIN process should be coordinated. For example, the creation of the template through extension of the cross-section or explicit specification of coordinates should be employed by both users.

The use of OTF-GPS automates tide data collection in the survey process, and thus reduces post-processing time and the possibility of error. The Coastal Oceanographics guide to this process, to be released in 1997, will provide detailed information on using such a system. Note that development of the necessary Kinematic Tidal Diagram requires a geodetic survey of tide gages in the survey area. This automated system also requires use of OTF-GPS, which mandates establishment of a user base differential station (current broadcast networks are not compatible with OTF).

Users that have or can obtain an OTF-GPS system are encouraged to begin using the OTF-GPS Tide system. Initial results should be compared to conventional tide readings to verify the tide diagram and processing procedures. USACE users should contact TEC if assistance is needed with gage surveys, system installation or use. Non-USACE users should contact Coastal Oceanographics if further guidance is needed.

The HYPACK integration of multibeam systems offers users a familiar interface to a complex new survey technology. Users can use the familiar PC computer with Windows operating system to plan, conduct and post-process surveys, and export data in formats compatible with past survey systems and processes. The patch test offers a simple test to calibrate the sounding systems and identify errors in all or some of the beams.

However, users should note that multibeam systems are considerably more complex than single beam systems, and use of the former in shallow water (less than 100 feet) is relatively new. As the angle of the beams with the vertical increases, error in depth measurement also increases. Although multibeam manufacturers claim swath widths of five times the water depth or greater, beam angles greater than 45° should be analyzed carefully for errors greater than 0.5 foot. Users should also note that the price of virtually total bottom coverage is very large data sets that may be impossible to edit or use in analyses.

Multibeam systems should be used in areas where specific detail is needed, such as scour sites, breakwater or revetment surveys; or particularly high accuracy is needed for dredge surveys, such as rock cut applications. Frequent error checks, such as patch tests, should be used if 0.5 foot accuracy is needed, particularly if swath widths greater than twice the water depth are being used. Users should consult the multibeam training course documents listed in the References for further information on multibeam technology.

The cross-check data editing routine in HYPACK enables evaluation of data consistency from single beam systems, which can help identify calibration errors, positioning problems, temperature or salinity variations in the water column, and other problems. The procedure is specified in the USACE Hydrographic Surveying Engineer Manual, EM 1110-2-1003, and the software routine in HYPACK provides a simple and efficient routine to accomplish the check. All users should begin using cross-check for quality control, and EM 1110-2-1003 should be referenced for recommended for cross-check line spacing and frequency.

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